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JP 020260589 A	US 6433920 B1
US 5266092 A	US 4400052 A
US 4389617 A	JP 20000133867 A

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(54) Abstract Title: **Raman optical waveguide with refractive index modified by ion implantation and fabrication method**

(57) A method for fabricating a waveguide (2), in a substrate 4 comprising a single-crystalline Raman material, comprising the step of altering the refractive index of a first region 8 at a predetermined depth within the substrate so as to define a waveguide region 10 disposed between the first region 8 and a first surface of the substrate, such that electromagnetic radiation introduced into the waveguide region 10 is confined therein. The first region may occupy a single predetermined depth (for a planar waveguide), or may vary in depth across a selected portion of the substrate 4 for a stripe waveguide. The step of altering the refractive index of the first region 8 comprises implanting ions into said region to impart an amorphous structure thereto. The Raman material may comprise potassium gadolinium tungstate. A Raman waveguide (2) fabricated by the foregoing method.

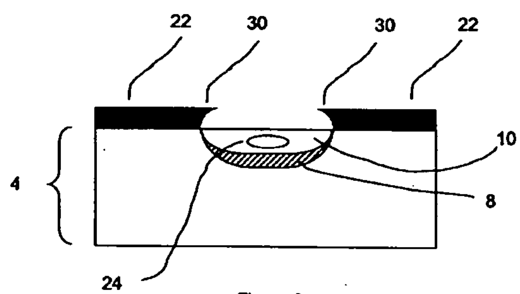

Figure 3

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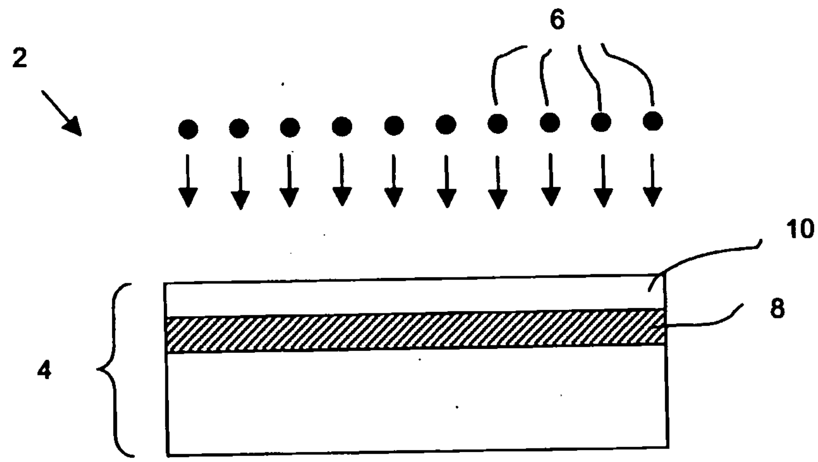

Figure 1

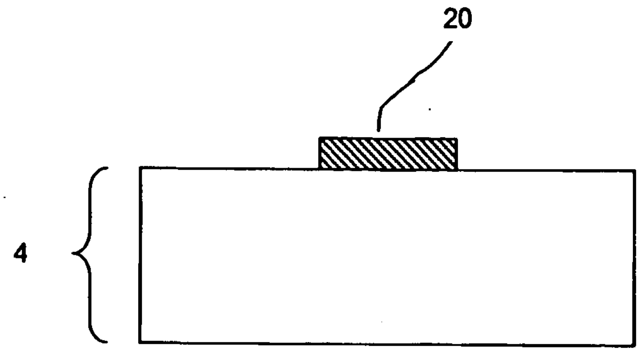

Figure 2a

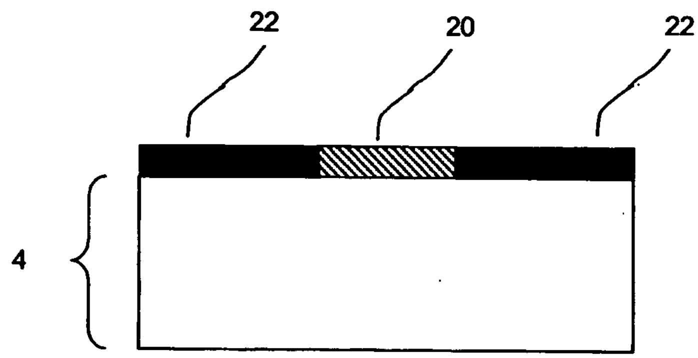

Figure 2b

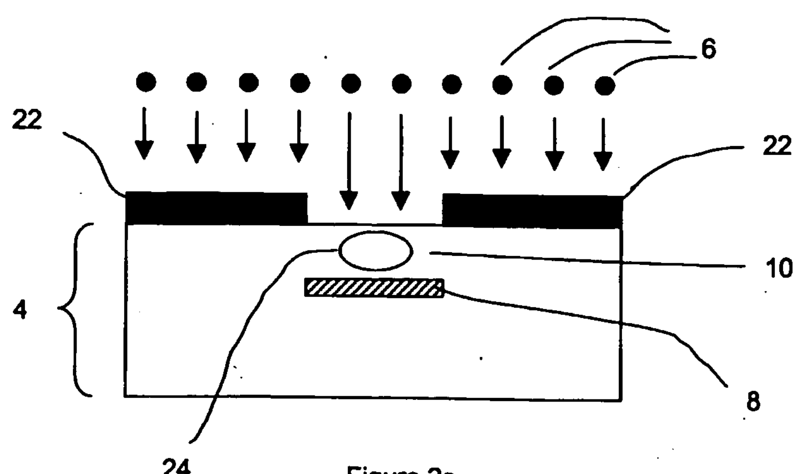

Figure 2c

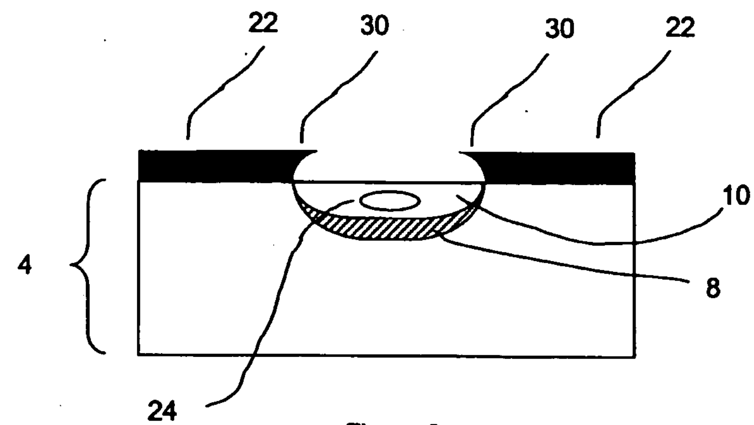

Figure 3

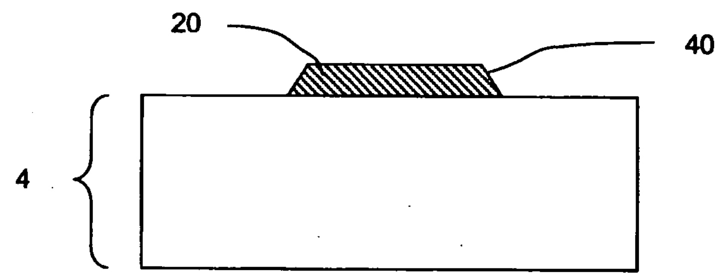

Figure 4a

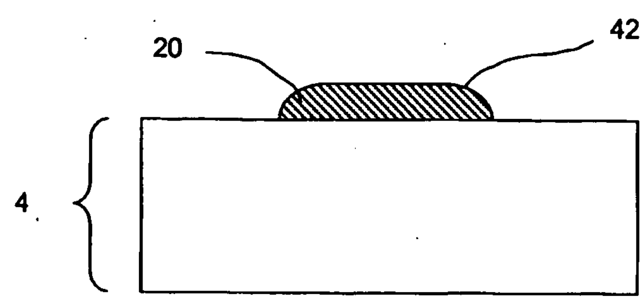

Figure 4b

RAMAN OPTICAL WAVEGUIDE

The present invention relates to Raman optical waveguides and to a method for fabricating said waveguides. The invention has particular relevance to the fabrication of stripe waveguides in single-crystal potassium gadolinium tungstate.

Optical devices which utilise Raman scattering are known, for example solid state lasers. Conventional devices may comprise an optical fibre having a composite core containing particles of Raman material incorporated into a couplant material, said core being surrounded by an outer sheath (for example, see GB00/04574).

Alternatively, devices are known which comprise a Raman waveguide disposed on a substrate. The waveguide may comprise a planar waveguide providing optical confinement in a single dimension or a stripe waveguide providing optical confinement in two-dimensions. The stripe waveguide may be fabricated by selectively removing the Raman material from the substrate using micro-machining techniques (for example, using ion beam etching). Alternatively, the stripe waveguide may be fabricated by selectively depositing the Raman material onto the substrate, for example using gas / vapour phase epitaxial growth, liquid phase epitaxial growth, chemical vapour phase deposition, or sputtering.

In the case of a Raman waveguide disposed on a substrate, the Raman material may be deposited by pulsed laser deposition. For example, potassium gadolinium tungstate (KGW) amorphous thin films have been deposited onto sapphire substrates using pulsed laser deposition [P A Atanasov, R I Tomov, J Perriere, R W Eason, N Vainos, A Klini, A Zherikhin, and W Millon, *'Growth of Nd:potassium gadolinium tungstate thin-film waveguides by pulsed laser deposition'*, Appl Phys Lett, 76 (18), pp2490-2492 (2000)]. The films have been shown to act as planar optical waveguides at a wavelength of 633nm.

The optical performance of the waveguides described above is, however, limited by optical losses inherent in the structure of the respective devices. For example, in the case of the fibre comprising particles of Raman material incorporated into a couplant material, losses occur within the couplant material between adjacent Raman particles. Similarly, in the case of the Raman waveguide fabricated by material deposition

techniques, the Raman material exhibits an amorphous or polycrystalline structure in which single crystal components have differing orientations. Optical losses occur at the crystal boundaries within the polycrystalline waveguide.

Furthermore, the non-linear optical properties of the amorphous or polycrystalline Raman material, so deposited, may be very small or non-existent impairing the performance of any resulting device.

It is an object of the present invention to mitigate at least some of the disadvantages of the foregoing Raman waveguide devices and fabrication methods. It is a further object of the present invention to provide an alternative method for fabricating a Raman waveguide.

According to a first aspect of the present invention, a method for fabricating a waveguide, in a substrate comprising a substantially single-crystalline Raman material, comprises the step of altering the refractive index of a first region at a predetermined depth within the substrate so as to define a waveguide region disposed between the first region and a first surface of the substrate, such that electromagnetic radiation introduced into the waveguide region is confined therein in at least one dimension.

The fabrication method according to the present invention provides improved device performance over conventional fabrication methods since the bulk single-crystalline properties of the substrate are retained within the waveguide region. Accordingly, the waveguide will replicate any non-linear/Raman process observed in the bulk form. Waveguide devices fabricated using the method described herein benefit from a higher concentration of optical signal in the waveguide region than would be afforded in a bulk single crystalline substrate only.

For the purpose of this specification, electromagnetic radiation shall include radiation having wavelengths in the visible part of the electromagnetic spectrum as well as radiation having wavelengths which fall outside the visible part of the electromagnetic spectrum, subject to the physical conditions required for the material to support optical modes.

Preferably, the step of altering the refractive index comprises reducing the refractive index of the first region with respect to the waveguide region.

Advantageously, the step of altering the refractive index comprises imparting a substantially amorphous structure to the Raman material within the first region of the substrate.

This step of altering the structure of the Raman material within the first region is simpler, and therefore more cost-effective, than conventional processing techniques, which typically involve adding another material to the substrate or removing material therefrom in order to form the waveguide.

In a preferred embodiment, the method comprises the step of altering the refractive index at a plurality of predetermined depths within a selected portion of the substrate, so as to form the first region around the waveguide region, such that electromagnetic radiation introduced into the waveguide region is confined therein in at least two dimensions.

This embodiment provides effective confinement of light within the undamaged waveguide layer by reducing leakage of light from the edges of the waveguide layer. The method provides a process for fabricating high-efficiency stripe waveguides.

When viewed in cross-section, the first region may comprise a channel shape or an arcuate shape, for example a crescent. In certain cases, the edges of the first region may intersect the first surface of the substrate.

Conveniently, the step of altering the refractive index comprises introducing ions into the first region of the substrate so as to alter the structure of the Raman material in the first region.

Where the refractive index is altered at a plurality of predetermined depths within a selected portion of the substrate, so as to form the first region around the waveguide region, the method advantageously comprises implanting ions into the first region through an implantation mask adapted to modify the range of the ions within the underlying substrate, wherein the thickness of the implantation mask is adapted to control the predetermined depth within the substrate at which the first region is formed.

The above implantation mask is advantageous in that ions may be implanted into the first region, at a plurality of predetermined depths, using a single ion implantation step.

Preferably, the implantation mask comprises at least one area having a tapering thickness, so as to vary the predetermined depths within the substrate, underlying said area, at which the first region is formed. The thickness of the implantation mask may taper linearly or non-linearly within the tapered area.

Where the implantation mask comprises at least one area having a tapering thickness, the method advantageously comprises the steps of

(i) patterning the surface of the substrate with a resist

(ii) applying the implantation mask to the surface of the substrate having the resist applied thereon,

(iii) removing the resist prior to the ion implantation step,

wherein the cross-section of the resist comprises at least one of a trapezoid, a section of a circle, a section of an ellipse and an elongate form having rounded corners

Conveniently, the implantation mask comprises gold.

Preferably, the ions comprise at least one of helium ions and hydrogen ions. The ions may be implanted into the first region of the substrate with energies in the range 0.5MeV - 2MeV, for He. The ions may be implanted into the first region of the substrate with dose levels in the range $5x10^{14}/cm^2$ -$5x10^{16}/cm^2$.

In a preferred embodiment, the Raman material comprises one of potassium gadolinium tungstate, barium titanate and diamond. The Raman material may comprise a doped Raman material having at least one dopant species incorporated therein. The dopant species may comprise at least one of neodymium and erbium.

According to a second aspect of the present invention, there is now proposed a waveguide device fabricated according to the method of the first aspect of the present invention.

According to a third aspect of the present invention, there is now proposed a Raman waveguide comprising a substrate of substantially single-crystalline Raman material, said substrate having a first region arranged at a predetermined depth within the

substrate and a waveguide region disposed between the first region and a first surface of the substrate,

wherein the respective refractive indices of the first region and the waveguide region are arranged such that, in use, electromagnetic radiation introduced into the waveguide region is confined therein in at least one dimension.

The above Raman waveguide capitalises on the fact that the bulk single-crystalline properties of the substrate are retained within the waveguide region. Accordingly, the Raman waveguide will replicate any non-linear/Raman process observed in the bulk form. The Raman waveguide benefits from a higher concentration of optical signal in the waveguide region.

In a preferred embodiment, the refractive index of the first region is less than that of the waveguide region.

In another preferred embodiment, the depth of the first region varies across a selected portion of the substrate, such that the first region is disposed around the waveguide region so as to confine electromagnetic radiation introduced into the waveguide region therein in at least two dimensions.

The above structure provides effective confinement of light within the undamaged waveguide layer by reducing leakage of light from the edges of the waveguide layer. This results in a high-efficiency stripe Raman waveguide.

Conveniently, the cross-section of the first region comprises at least one of a channel, an arcuate shape and a crescent.

Advantageously, the first region intersects the first surface of the substrate so as to completely enclose the waveguide region there between.

Preferably, the first region comprises a region of the substrate material having an amorphous structure.

This configuration is advantageous since the first region comprises the same material as the substrate, albeit with an amorphous structure rather than the single crystalline structure of the remaining substrate.

The Raman material may comprise one of potassium gadolinium tungstate, barium titanate and diamond. The Raman material may comprise a doped Raman material having at least one dopant species incorporated therein, for example neodymium or erbium.

According to a fourth aspect of the present invention, there is now proposed a Raman laser comprising a Raman waveguide according to the third aspect of the present invention.

According to a fifth aspect of the present invention, there is now proposed an optical amplifier comprising a Raman waveguide according to the third aspect of the present invention.

According to a sixth aspect of the present invention, there is now proposed a frequency-shifting device comprising a Raman waveguide according to the third aspect of the present invention.

The invention will now be described, by example only, with reference to the accompanying drawings in which;

Figure 1 shows a schematic cross-sectional view through a planar Raman waveguide during fabrication,

Figure 2 shows cross-sectional views through a stripe Raman waveguide during fabrication and illustrates schematically the sequential steps of the ion implantation process according to the method of the present invention,

Figure 3 shows a schematic cross-sectional view through a stripe Raman waveguide during fabrication using a gold pattern mask having profiled edges.

Figure 4 shows typical schematic cross-sectional views through the developed photo-resist prior to the step of depositing the gold layer onto the substrate.

Referring to Figure 1, the method according to the present invention for fabricating a Raman waveguide (2) utilises ion implantation of a substrate (4) to alter the refractive index of said substrate (4). Typically, the method of the present invention comprises implanting ions (6) into a crystalline substrate (4) comprising a single-crystal of Raman material. For example, the substrate may comprise potassium gadolinium tungstate (also referred to as KGW), diamond, barium titanate or any other Raman material capable of generating Stokes lines and / or Anti-Stokes lines. The substrate (4) may be grown by any conventional technique, for example Czochralski growth.

The Raman material may have dopants introduced therein, in low concentration, without affecting the single-crystal structure. For example, the single-crystalline substrate (4) may be doped with rare earth elements, such as neodymium and erbium. Such doped Raman materials find particular application in Raman laser devices.

The method of the present invention relies on the use of a low-energy, ion implantation procedure, to implant ions (6) under the surface of the crystalline substrate (4). During the implantation procedure, the ions interact with lattice ions in the substrate to form a damaged layer (8) in the substrate (4). In contrast to the bulk of the single-crystalline substrate, the damaged layer comprises amorphous material. The damaged layer (8), typically, has a lower refractive index than the upper layer (10) and accordingly the upper layer acts as an optical waveguide. Light may be propagated in the upper layer (10) and will be confined to said layer by total internal reflection at the interfaces between the upper layer (10) and the underlying damaged layer (8) and the upper layer (10) and the surrounding air.

In practice, ions (6) having a low atomic weight, for example helium ions or protons, are implanted into the substrate (4). As the ions (6) pass into the substrate (4), energy is transferred to the substrate (4) primarily by electronic excitation. Near the end of the ion track, however, nuclear collisions displace lattice ions in the substrate (4), inducing damage (8) therein. The damaged layer (8), typically, has a lower refractive index than the surface above, the refractive index profile tracking the damage profile (which is typically Gaussian). The upper layer (10), being of a higher refractive index, can therefore act as an optical waveguide.

The ion implantation procedure typically comprises the following steps. The substrates (typical dimensions 1.5mm x 12mm x 25mm) are cleaned using a typical solvent-based clean-room procedure. ^{3}He ions are implanted into the substrate, normal to the surface, at an energy of 2MeV and a dose of $1x10^{16}/cm^2$ (beam current < 1μA, vacuum pressure ~ $5x10^{-7}$Torr, room temperature). Heating of the substrate by the ion beam is minimised by mounting the substrate on graphite paper.

The ion implantation range, and hence the depth at which the damaged layer (8) occurs within the substrate, may be controlled by varying the process conditions, for example the ion species and the implantation energy. Additionally, or alternatively, an implantation mask may be used to reduce the range of the ions (6).

In the case of a planar waveguide, ions (6) are implanted over substantially the entire surface of the substrate (4). Alternatively, ions (6) may be selectively implanted into the substrate (4) to form a waveguide providing optical confinement in two dimensions (a stripe waveguide).

A planar Raman waveguide fabricated using the foregoing method was assessed by the prism-coupling technique (using a strontium titanate prism), at 488nm and 633nm. Propagation was along the [010] direction. Waveguiding was evinced by the observation of m-lines, corresponding to modes propagating within the high index region (10). Full mode indices are summarised as follows:

488nm: 6 TE modes and 6 TM modes, estimated surface indices of 2.3101 (TE) and 2.139 (TM).

633nm: 5 TE modes and 5 TM modes, estimated surface indices of 2.059 (TE) and 2.094 (TM).

Referring to Figure 2, the process for fabricating a stripe waveguide typically comprises sequential stages during which specific areas of the substrate are implanted with ions.

Referring specifically to Figure 2a, the waveguide is fabricated in a single-crystalline substrate (4) of Raman material. The substrate (4) of Raman material is first coated

with a (nominally) 0.1μm thick titanium-gold alloy seed layer (not shown in Figure 2). The seed layer may be deposited by any conventional deposition technique, for example sputtering. A conformal layer of photo-resist (20) is then applied to the Raman substrate (4) and patterned using conventional photolithography. For example, the photo-resist (20) may be exposed through a mask to define areas which will subsequently be implanted with ions. Alternatively, the photo-resist (20) may be patterned directly using an electron beam (electron-beam writing). The photo-resist (20) is developed in the conventional manner.

Referring specifically to Figure 2b, the substrate is coated with a (nominally) 4μm thick gold layer (22). The gold may be deposited by electroplating onto the seed layer or any alternative conventional deposition technique, for example sputtering. The gold layer (22) is deposited only on exposed areas of the substrate (4), i.e. those areas not covered by the photo-resist (20).

Referring to Figure 2c, the remaining photo-resist (20) is removed from the substrate (4) to reveal areas of gold (nominally 4μm thick, for helium ions implanted at 2MeV) which form the mask for the ion implantation process. The gold layer (22), hereinafter referred to as the gold pattern mask, obscures the underlying substrate during the ion implantation process. The gold pattern mask (22) acts a barrier to the impinging ^{3}He ions, in effect decreasing the ion range within the substrate immediately under the gold. By controlling the thickness of the gold pattern mask (22), regions underneath the gold mask can be kept substantially free of implanted ions. After implantation, the gold pattern mask and seed layer are removed by etching in a solution of potassium iodide.

Light may be propagated in the region (24) above the damaged layer (8) and will be confined to said region by total internal reflection at the interface between the upper undamaged layer (10) and the underlying damaged layer (8), and the upper undamaged layer (10) and the surrounding air.

The ion implantation process may also involve actively controlling the direction of the ion beam (a process known as ion beam writing) to augment the effect of the gold ion implantation mask, thereby improving the effectiveness of the ion implantation process.

The ion implantation process may be further controlled by altering the ion implantation energy or by utilising different species of ions. Typically, for helium ions, the ion implantation energy will be in the range 0.5MeV to 2MeV. Moreover, ions may be implanted using multiple ion implantation energies to achieve a particular profile of implanted ions at differing depths within the substrate (4).

In addition to altering the ion implantation energy, alternative species of ions may be employed. For example any low atomic mass ions may be substituted for the ^{3}He ions, such as protons.

A series of stripe waveguides may be produced by patterning the substrate in an appropriate manner as described above.

Effective confinement of light at the edges of the undamaged waveguide layer (10) is an important factor governing the efficiency of a stripe waveguide produced by the above method. Accordingly, in order to reduce leakage of light from the edges of the undamaged waveguide layer (10), the underlying damaged layer (8) may have a profile added thereto during fabrication. The depth of the damaged layer (8) may be altered at the edges. For example, the edges of the damaged layer (8) may be extended upwards towards the top surface of the substrate. When viewed in cross-section, the damaged layer (8) may comprise a channel shape or an arcuate shape, for example a crescent. In the limit, the edges of the damaged layer (8) may intersect the top surface of the substrate.

The profiled damaged layer (8) may be fabricated by varying the angle at which the ions are implanted into the substrate. Additionally, or alternatively, the profile may be created by ion beam writing in conjunction with varying the ion implantation energy. A multi-stage implantation process could also be employed in which an additional mask is used to separately define the edges of the damaged layer (8).

Referring to Figure 3, an alternative method for fabricating a stripe waveguide comprises applying a profile to the side-walls (30) of the gold pattern mask (22), such that the impinging ions travel through a varied thickness of gold at the edge of the pattern mask (22). This creates a fringe-effect in the substrate (4), whereby ions are

implanted into the substrate at various depths corresponding to the thickness of the gold pattern mask (22). This spread in the ion implantation depth results in a variation of the refractive index with depth. This effect, coupled with the Gaussian spread in the ion-induced damage profile, gives rise to stripe waveguide optical confinement in the device.

Light may be propagated in the region (24) above the damaged layer (8) and will be confined to said region by total internal reflection at the interface between the upper undamaged layer (10) and the underlying damaged layer (8). The profile of the damaged layer produced by the method according to this embodiment of the present invention provides effective confinement of light within the waveguide.

The side-walls (30) of the gold pattern mask (22) may be profiled by altering the shape of the developed photo-resist (20) prior to the step of depositing the gold layer (22) onto the substrate (4). For example, when viewed in cross-section, the developed photo-resist (20) may comprise a trapezoid (40) form (see Figure 4a). Alternatively, when viewed in cross-section, the profile (42) of the developed photo-resist (20) may resemble a section of a circle, a section of an ellipse or an elongate form having rounded corners (Figure 4b refers).

The appropriate profile may be imparted to the photo-resist (20) during exposure of said photo-resist, for example by using optical means (diffraction grating etc.). Alternatively, in the case of an arcuate cross-sectional profile (section of a circle, a section of an ellipse or an elongate form having rounded corners), the photo-resist (20) may be subjected to a low temperature heating step (heat to approximately 100° Celsius) to soften the photo-resist sufficiently to flow into the desired profile.

To assess for stripe waveguide confinement, the facets of the substrate were polished to enable the coupling of laser light into and out of the stripe region (24) using the end-fire coupling technique. The technique utilised two microscope objectives, one at the input, to focus the light onto the end facet of the waveguide, the other at the output to image the end of the waveguide. Mode excitation occurs when the conditions for total internal reflection within the waveguide region (24) are satisfied, this arising because the refractive index of the waveguide region (24) is higher than the surrounding material (the underlying amorphised area (8) and air

above the substrate (4)). The position of each microscope objective was optimised such that the light transmitted in the waveguide was maximised.

Different waveguide widths, ranging from 1μm up to 80μm, were fabricated in the gold masking layer (22). Waveguiding was observed in a range of stripes varying in width from 6.5μm to 10μm, and in an 80μm wide stripe and a 1mm wide stripe. Transmission losses were low, with very little scattering from the surface of the waveguide.

The fabrication method according to the present invention provides improved device performance over conventional fabrication methods since the bulk single-crystalline properties of the substrate are retained within the waveguide region. Accordingly, the waveguide will replicate any non-linear/Raman process observed in the bulk form. Waveguide devices fabricated using the method described herein benefit from a higher concentration of signal in the waveguide region.

The method described herein is suitable for fabricating Raman waveguide devices for a range of applications including lasers, optical amplifiers, and wavelength converters.

Claims

1. A method for fabricating a waveguide, in a substrate comprising a substantially single-crystalline Raman material, comprising the step of altering the refractive index of a first region at a predetermined depth within the substrate so as to define a waveguide region disposed between the first region and a first surface of the substrate, such that electromagnetic radiation introduced into the waveguide region is confined therein in at least one dimension.

2. A method according to claim 1 wherein the step of altering the refractive index comprises reducing the refractive index of the first region with respect to the waveguide region.

3. A method according to claim 1 or 2 wherein the step of altering the refractive index comprises imparting a substantially amorphous structure to the Raman material within the first region of the substrate.

4. A method according to any of the preceding claims comprising the step of altering the refractive index at a plurality of predetermined depths within a selected portion of the substrate, so as to form the first region around the waveguide region, such that electromagnetic radiation introduced into the waveguide region is confined therein in at least two dimensions.

5. A method according to any of the preceding claims wherein the step of altering the refractive index comprises introducing ions into the first region of the substrate so as to alter the structure of the Raman material in the first region.

6. A method according to claim 5, when dependent on claim 4, comprising implanting ions into the first region through an implantation mask adapted to modify the range of the ions within the underlying substrate, wherein the thickness of the implantation mask is adapted to control the predetermined depth within the substrate at which the first region is formed.

7. A method according to claim 6 wherein the implantation mask comprises at least one area having a tapering thickness, so as to vary the predetermined depths within the substrate, underlying said area, at which the first region is formed.

8. A method according to claim 7 wherein the thickness of the implantation mask tapers linearly within the tapered area.

9. A method according to claim 8 wherein the thickness of the implantation mask tapers non-linearly within the tapered area.

10. A method according to any of claims 7 – 9 comprising the steps of

(i) patterning the surface of the substrate with a resist,

(ii) applying the implantation mask to the surface of the substrate having the resist applied thereon,

(iii) removing the resist prior to the ion implantation step,

wherein the cross-section of the resist comprises at least one of a trapezoid, a section of a circle, a section of an ellipse and an elongate form having rounded corners

11. A method according to any of claims 6 – 10 wherein the implantation mask comprises gold.

12. A method according to any of claims 5 - 11 wherein the ions comprise at least one of helium ions and hydrogen ions.

13. A method according to any of claims 5 - 12 wherein the ions are implanted into the first region of the substrate with energies in the range 0.5MeV - 2MeV.

14. A method according to any of claims 5 - 13 wherein the ions are implanted into the first region of the substrate with dose levels in the range $5x10^{14}/cm^2$ – $5x10^{16}/cm^2$.

15. A method according to any of the preceding claims wherein the Raman material comprises one of potassium gadolinium tungstate, barium titanate and diamond.

16. A method according to any of the preceding claims wherein the Raman material comprises a doped Raman material having at least one dopant species incorporated therein.

17. A method according to claim 16 wherein the dopant species comprises at least one of neodymium and erbium.

18. A waveguide device fabricated according to the method of any of claims 1 – 17.

19. A method for fabricating a waveguide substantially as herein before described with reference to figures 1-4 of the accompanying drawings.

20. A Raman waveguide comprising a substrate of substantially single-crystalline Raman material, said substrate having a first region arranged at a predetermined depth within the substrate and a waveguide region disposed between the first region and a first surface of the substrate,

wherein the respective refractive indices of the first region and the waveguide region are arranged such that, in use, electromagnetic radiation introduced into the waveguide region is confined therein in at least one dimension.

21. A Raman waveguide according to claim 20 wherein the refractive index of the first region is less than that of the waveguide region.

22. A Raman waveguide according to claim 20 or 21 wherein the predetermined depth at which the first region is arranged varies across a selected portion of the substrate, such that the first region is disposed around the waveguide region so as to confined electromagnetic radiation introduced into the waveguide region therein in at least two dimensions.

23. A Raman waveguide according to claim 22 wherein the cross-section of the first region comprises at least one of a channel, an arcuate shape and a crescent.

24. A Raman waveguide according to claim 22 or 23 wherein the first region intersects the first surface of the substrate so as to completely enclose the waveguide region there between.

25. A Raman waveguide according to any of claims 20 - 24 wherein the first region comprises a region of the substrate material having an amorphous structure.

26. A Raman waveguide according to any of claims 20 – 25 wherein the Raman material comprises one of potassium gadolinium tungstate, barium titanate and diamond.

27. A Raman waveguide according to any of claims 20 – 26 wherein the Raman material comprises a doped Raman material having at least one dopant species incorporated therein.

28. A method according to claim 27 wherein the dopant species comprises at least one of neodymium and erbium.

29. A Raman laser comprising a Raman waveguide according to any of claims 20 – 28.

30. An optical amplifier comprising a Raman waveguide according to any of claims 20 –28.

31. A frequency-shifting device comprising a Raman waveguide according to any of claims 20 – 28.

32. A Raman waveguide substantially as herein before described with reference to figures 1-4 of the accompanying drawings.

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Application No:	GB 0224853.2	**Examiner:**	Mark Gainey
Claims searched:	1-32	**Date of search:**	18 February 2003

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Patents Act 1977 : Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance	
A	-	US 6433920 B1	WELCH et al. see abstract, col.2 ll.32-47
X,Y	X:1,20 Y:5-18,26-32	US 5266092	BIERLEIN et al. see abstract.
X,Y	X:1,5,20 Y:5-18,26-32	US 4400052	ALFERNESS et al. see abstract, col.3 ll.31-51
A	-	US 4389617	KURNIT see abstract.
A	-	JP 2000133867	SEMICONDUCTOR RES. FOUND. see abstract.
A	-	JP 2260589	POWER REACTOR & NUCLEAR FUEL see abstract.

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Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC[V]:

G2F

Worldwide search of patent documents classified in the following areas of the IPC[7]:

G02F

The following online and other databases have been used in the preparation of this search report:

EPODOC, JAPIO, WPI